PIBS 1574

Industrial Waste Diversion Program

Final Reports #7

PRELIMINARY EVALUATION OF COPPER, NICKEL AND CHROMIUM RECOVERY FROM WASTES GENERATED BY THE METAL FINISHING INDUSTRY IN ONTARIO

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INDUSTRIAL WASTE DIVERSION PROGRAM

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Report Prepared For:

Waste Management Branch
Ontario Ministry of the Environment

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PRELIMINARY EVALUATION OF COPPER, NICKEL, AND CHROMIUM RECOVERY FROM WASTES GENERATED BY THE METAL FINISHING INDUSTRY IN ONTARIO

Report Prepared For:

Waste Management Branch
Ontario Ministry of the Environment

In Consultation With:

Metallurgical Consultant

Report Prepared By:

R. P. Pyne
Suite 1304 - 250 Queen's Quay West
Toronto, Ontario
M5J 2N2

DISCLAIMER

This report is in partial fulfillment of conditions of a grant given to R. L. Pyne Metallurgical Consultant by the Ministry of the Environment under the Industrial Waste Diversion Program. The report was prepared by R. L. Pyne Metallurgical Consultant and documents results of work for which the Ministry of the Environment provided financial assistance.

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INDEX

		Page No.
1.0	INTRODUCTION	1-1
2.0	SUMMARY AND CONCLUSIONS	2-1
3.0	RECOMMENDATIONS	3-1
4.0	SURVEY OF SLUDGE GENERATORS IN SOUTHERN ONTARIO	4-1
5.0	SLUDGE PROCESSING	
	5.1 EXPERIMENTAL PROGRAMME	5-1
	5.2 METALLURGICAL BALANCE AND PRODUCTION SCHEDULE	5-6
	5.3 PROCESS PLANT	5-8
	5.3.1 Process Description	5-8
	5.3.2 Design Criteria	5-15
6.0	CAPITAL COST ESTIMATE	
	6.1 BASIS OF ESTIMATE	6-1
	6.2 CAPITAL COST ESTIMATE SUMMARY	6-1
	6.3 PLANT EQUIPMENT LIST	6-3
	6.4 INDIRECT COSTS	6-7
	6.4.1 Initial Inventory of Spares	6-7
	6.4.2 Consultants, Environment	6-7
	6.4.3 Construction Indirects	6-7
	6.4.4 Engineering and Construction Management	6-7
	6.4.5 Contingency	6-7
	6.4.6 Head Office Costs	6-8
	6.5 WORKING CAPITAL	6-8
	6.6 COMMENTS ON CAPITAL COST ESTIMATE	6-8
7.0	OPERATING COST ESTIMATE	
	7.1 PLANT DIRECT OPERATING COST SUMMARY	7-2
	7.2 PLANT DIRECT OPERATING COST - STAFF AND LABOUR	7-2
	7.3 PLANT DIRECT OPERATING COST - OPERATING SUPPLIES	7-2
	7.4 PLANT DIRECT OPERATING COST - MAINTENANCE AND MISCELLANEOUS SUPPLIES	7-3
	7.5 PLANT DIRECT OPERATING COST - POWER	7-3
	7.6 INDIRECT PLANT OPERATING COSTS	7-4
	7.7 COMMENT ON OPERATING COST	7-4

INDEX

			Page No.
8.0	PRODUCT MARKETING		
	8.1	COPPER AND NICKEL SULPHIDE CONCENTRATES	8-1
		8.1.1 Inco Net Smelter Return for Nickel Sulphide Concentrate	8-2
		8.1.2 Inco Net Smelter Return for Copper Sulphide Concentrate	8-4
		8.1.3 Total Inco Net Smelter Return/ tonne Plant Feedstock	8-6
	8.2	CHROMIUM HYDROXIDE PRECIPITATE	8-6
		8.2.1 Chromium Hydroxide Price	8-7
		8.2.2 Chromium Hydroxide Revenue	8-8
	8.3	TOTAL SALES REVENUE	8-8
		8.3.1 Transportation of Products	8-8
		8.3.2 Total Sales Revenue	8-8
9.0	ECONOMIC EVALUATION		
	9.1	PRODUCTION	9-1
	9.2	REVENUE	9-1
	9.3	OPERATING PROFIT	9-1
	9.4	CORPORATION TAXES	9-2
	9.5	NET EQUITY CASH AVAILABLE	9-2
10.0	REFERENCES		

APPENDICES

1.0 ANALYSIS OF SLUDGE SAMPLES BY ASSAYERS' ONTARIO

2.0 INCO PURCHASE TERMS FOR COPPER AND NICKEL SULPHIDE CONCENTRATES

3.0 METALLURG (CANADA) LIMITED TERMS FOR PURCHASE OF CHROMIUM HYDROXIDE

LIST OF EXHIBITS

		Page No.
EXHIBIT 4.1	QUANTITY AND COMPOSITION OF WASTE SLUDGE GENERATED BY THE 15 LARGEST Cu-Ni-Cr PLATERS IN SOUTHERN ONTARIO	
EXHIBIT 5.1	SODIUM HYDROXIDE LEACHING OF SLUDGE	
EXHIBIT 5.2	SULPHURIC ACID LEACHING OF SLUDGE	
EXHIBIT 5.3	HYDROCHLORIC ACID LEACHING OF SLUDGE	
EXHIBIT 5.4	ANALYSIS OF CHROMIUM PREGNANT SOLUTION	
EXHIBIT 5.5	PROJECTED ANNUAL METAL BALANCE	
EXHIBIT 5.6	FLOWSHEET NO. 1 - PUG MILLING, LEACHING, Ni-Cu PRECIPITATION AND FILTRATION	
EXHIBIT 5.7	FLOWSHEET NO. 2 - $Cr(OH)_3$ PRECIPITATION AND FILTRATION	
EXHIBIT 9.1	CASHFLOW SUMMARY	

SECTION 1.0

INTRODUCTION

SECTION 1.0

INTRODUCTION

Current legislation in Ontario imposes stringent limitations on the concentration of copper, nickel and chromium in electroplating shop effluents which may be discharged to municipal sewer systems. Most copper-nickel-chromium electroplaters comply with this legislation by treating their rinse streams to produce a metal hydroxide sludge which is classified as hazardous waste and impounded in secure landfills. Sludge transportation and disposal fees at landfill sites are currently in the vicinity of $250.00/metric tonne (dry basis) and are expected to increase significantly in future.

The purpose of this study was to establish the quantity and composition of sludge generated in southern Ontario and to prepare a preliminary economic evaluation of centralized processing of sludge to produce metal concentrates or intermediate for sale to existing markets.

The original concept was to effect a physical separation of the individual metal hydroxide species by a differential froth flotation process. Experimental work confirmed that this was not feasible due to the existence of the various metal hydroxides as bound co-precipitates, rather than separate and discrete particles. Subsequent experimental work provided the basis for a hydrometallurgical process which gave high extraction of the three metals from the sludge and which permitted a selective precipitation of the metals from solution into separate marketable concentrates.

This report contains the results of a survey of available sludge in southern Ontario, design criteria for a centralized processing plant, estimated capital and operating costs for the project, typical sales terms for the plant's products, and a project cash flow summary.

SECTION 2.0

SUMMARY AND CONCLUSIONS

SECTION 2.0

SUMMARY AND CONCLUSIONS

The survey of copper-nickel-chromium plating shops in southern Ontario was limited to the 15 largest operations. The survey established that these shops generate approximately 7,800 tonnes of sludge (dry basis) annually, and that the mean composition of this sludge is 4.93% Cu, 15.99% Ni and 12.96% Cr.

A hydrochloric acid leaching process will extract at least 96.0% of the Cu, 99.0% of the nickel, and 95.0% of the chromium. Sulphide precipitation of Ni and Cu will yield products which can be sold to the Inco smelter at Copper Cliff, Ontario. Subsequent precipitation of chromium with caustic soda will give a chromium hydroxide product which can be marketed to chromium chemical or chromium refractories producers as a replacement for chromite ore.

Based on current metal prices and sales terms, sales revenue from these three products will be $1,659.00 per tonne of sludge processed. Operating costs will amount to $858.00 per tonne of sludge processed. Total capital costs for the process plant are estimated to be $6,930,800. A ten-year cash flow projection indicates a discounted cash flow rate of return on investment of 81.75% and a capital payback period of 2.2 years.

This preliminary evaluation indicates that a centralized processing plant for Cu-Ni-Cr electroplating sludges in southern Ontario would be a viable alternative to the current practice of landfill disposal of the sludge.

Process economics are very sensitive to hydrochloric acid costs. The availability of waste hydrochloric acid for use in the process should be thoroughly investigated.

SECTION 3.0

RECOMMENDATIONS

SECTION 3.0

RECOMMENDATIONS

The process developed for metals extraction, hydrochloric acid leaching and selective precipitation, is basically simple and few scale-up problems exist. However, critical aspects of the process which require further work include:

1. Characterization of the leach residue products as hazardous/non-hazardous.

2. Complete analysis and determination of the physical properties (sizing, etc.) of the products to be marketed.

The solid residue from hydrochloric acid leaching, being the product of an intensive leaching process, should, if thoroughly washed following filtration, be an inert product suitable for disposal in a local municipal waste landfill. However, tests will be required to confirm that any leachate from the residue does not have heavy metal concentrations above the legal limit.

Larger scale precipitation tests on the leach liquor will be required to provide suitable samples of the Ni-Cu sulphide precipitates for evaluation by the potential purchaser. The most critical element here is expected to be the efficiency of chloride elimination by thorough washing of the filter cakes. Chlorides are objectionable in the smeltering process and financial penalties will apply to chloride content over a certain level. Drying tests are also essential to ensure that a nodulized product free of excessive fines can be produced in an industrial scale rotary dryer.

It will also be necessary to confirm the precise Cr, Fe and Si content of the $Cr(OH)_3$ precipitate by further bench scale testing and to produce reasonable quantities of sample for evaluation by chromium chemical producers.

SECTION 4.0

SURVEY OF SLUDGE GENERATORS IN SOUTHERN ONTARIO

SECTION 4.0

SURVEY OF SLUDGE GENERATORS IN SOUTHERN ONTARIO

The quantity and composition of neutralized sludge generated by treatment of rinse streams from copper-nickel-chromium and nickel-chromium electroplating shops in Southern Ontario was unknown at the commencement of the project. A very imprecise estimate had been made on the basis of data derived from a 1974 survey of the Canadian metal finishing industry(1). This estimate suggested that an adequate quantity of waste sludge of sufficiently high nickel and chromium content was available to permit economic extraction of these metals. Consequently, the first activity in the execution of the project involved a survey of Cu-Ni-Cr platers in Southern Ontario to confirm the volume and composition of sludge which would be available in 1988 to a centralized processing plant extracting Ni, Cr and Cu for sale to existing markets.

The consultant visited 15 of the largest Ni-Cr and Cu-Ni-Cr platers in Southern Ontario for the purpose of obtaining precise data on the quantity, moisture content, and analysis of sludge generated by these platers. Samples of sludge were obtained from the plating shops for the purpose of Cu-Ni-Cr-Zn analysis and for use in the laboratory experimental programme. A standard questionnaire was prepared which registered data on historical quantity of sludge generated, projected quantity of sludge to be generated in future, composition of sludge, moisture content, type of waste treatment process, etc.

A December 1987 Environment Canada Survey of the Canadian Surface Finishing Industry(2) established that there are about 100 Cu-Ni-Cr and Ni-Cr platers in Ontario. However, many of these plating operations were very small and the 15 platers visited by the consultant probably account for at least 80% of the sludge generated in Ontario. The quantity of sludge (dry basis) generated by these 15 (21,550 kgs/calendar day) was used as the design basis of a hypothetical centralized metal recovery plant.

Exhibit 4.1, "Quantity and Composition of Waste Sludge Generated by the 15 Largest Cu-Ni-Cr and Ni-Cr Plating Shops in Southern Ontario", is based on volume of sludge shipped by these platers for disposal and on determination of H_2O content and analysis for Cu-Ni-Cr-Zn carried out by Assayers' Ontario Limited on representative samples of sludge obtained from the plating shops. (See also Appendix 1.0, "Analysis of Sludge Samples by Assayers' Ontario".)

It should be noted that most of the volume of Cu-Ni-Cr plating (and waste generation) in Ontario is concentrated in the shops of a few large operations. The four largest plating shops (Samples B, F, G and H) contribute 84% of the total weight of sludge and account for 83% of the nickel, 87% of the copper and 92% of the chromium contained in all sludge produced by the 15 platers.

EXHIBIT 4.1 - ANNUAL QUANTITY AND COMPOSITION OF WASTE SLUDGE GENERATED BY 15 LARGEST Cu-Ni-Cr ELECTROPLATERS IN SOUTHERN ONTARIO

Sample Number	Annual Volume Shipped (M^3)	Wet Weight (Tonnes)	Dry Weight (Tonnes)	Analysis %				Metal Weight (Tonnes)			
				Ni	Cu	Cr	Zn	Ni	Cu	Cr	Zn
A	122.33	156.83	125.89	29.19	.57	8.71	.12	36.75	.72	10.97	.15
B	3677.41	4714.44	2655.45	12.83	7.27	21.12	.10	340.69	193.05	560.83	--
C	87.16	111.74	73.69	1.95	.32	2.62	11.40	1.44	.24	1.93	8.40
D	279.06	357.75	311.71	27.34	5.07	9.18	.53	85.2	15.80	28.61	1.65
EA	77.49	99.34	12.56	9.31	1.90	6.69	5.18	1.17	.24	.84	.65
EB	51.66	66.23	52.03	13.95	1.99	19.45	.39	7.26	1.04	10.12	.20
F	2385.42	3058.11	1597.25	18.45	1.47	7.26	.26	294.69	23.48	115.96	4.15
G	795.14	1019.37	396.03	18.98	3.77	3.97	.18	75.17	14.93	15.72	.71
H	4185.96	5366.40	1955.52	16.76	5.32	12.36	.96	327.75	104.03	241.70	18.77
I	91.75	117.62	31.53	11.14	7.73	8.07	2.46	3.51	2.44	2.54	.78
J	103.36	132.51	58.38	13.93	3.49	17.34	1.43	8.13	2.04	10.12	.83
K	238.54	305.81	95.11	6.64	4.25	2.86	6.76	6.32	4.04	2.72	6.43
L	367.97	471.74	233.28	11.88	4.62	.05	.33	27.71	10.78	.1166	.77
M	220.78	283.04	168.10	13.94	.92	4.17	10.12	23.43	1.55	7.01	17.01
N	103.36	132.51	99.54	18.47	13.33	10.20	2.99	18.39	13.27	10.15	2.98
	12787.39	16396.44	7866.07	15.99	4.93	12.96	.81	1257.63	387.65	1019.34	63.48

SECTION 5.0

SLUDGE PROCESSING

SECTION 5.0

SLUDGE PROCESSING

5.1 EXPERIMENTAL PROGRAMME

The proposal submitted for this project had as its basis the application of the froth flotation process to produce separate concentrates of Cu, Ni and Cr hydroxides for sale to primary base metal smelter and chromium chemical plants. This proposal was predicated on the assumption that most of the metal hydroxides occurred as discrete particles which would be amenable to a physical separation process. A substantial experimental programme with the objective of producing such separate metal concentrates failed to achieve acceptable separation of Cu, Ni and Cr due to the fact that the metal hydroxides occurred chiefly as co-precipitates and therefore were not amenable to a physical separation process. As the flotation work was not successful in producing separate metal concentrates, it will not be reported here. The test results are included in an Appendix volume, however.

Since flotation separation of the hydroxide precipitates was not possible, it was necessary to consider hydrometallurgical (leaching) approaches to metal extraction. Initial tests attempted to solubilize the metals using caustic soda as the lixiviant. This approach was unsuccessful giving negligible metal extraction; typical test conditions and results are given in Exhibit 5.1 on the following page.

The next series of tests attempted to solubilize the metals using sulphuric acid as the lixiviant. This route also resulted in very low metal extractions under the conditions selected, and typical experimental results are given in Exhibit 5.2 on the following page.

The final approach selected was hydrochloric acid leaching of the hydroxide sludge. Leaching of all metals with high extraction in a relatively short time was achieved and typical results are reported in Exhibit 5.3.

EXHIBIT 5.1

SODIUM HYDROXIDE LEACHING OF SLUDGE

Test Number	Time (hrs)	NaOH Concentration	Temperature (°C)	Extraction (%) Cr	Cn	Ni
B-20	6.0	1.0 N	20	1.0	1.0	1.0
B-21	3.0	1.0 N	20	1.0	1.0	1.0
B-22	.75	1.0 N	95	1.0	1.0	1.0

EXHIBIT 5.2

SULPHURIC ACID LEACHING OF SLUDGE

Test Number	Time (hrs)	pH	Temperature (°C)	Extraction (%) Cr	Cu	Ni
B-23	2.0	2.0	95	6.72	26.89	17.93
B-24	6.0	2.0	20	1.0	1.0	3.55
B-25	4.0	2.0	20	1.0	1.0	2.30

EXHIBIT 5.3

HYDROCHLORIC ACID LEACHING OF SLUDGE

Leaching Procedure: 16.5 gms (dry basis) of Sample H digested in 500 ml of a 3.0% HCl solution for one hour in a laboratory mixer. Terminal pH was .7. The leach pulp was filtered with no washing of residue.

Precipitation Procedure: 294 ml of a 25% Na_2S solution was added to precipitate Cu at pH 1.15. The precipitate was filtered with no washing.

A further 75 ml of Na_2S solution was added in stages to provide three nickel precipitates which were filtered separately. Final pH was 4.0.

Metallurgical Results

Test Product	Weight (gms)	Analysis (%) Cu	Ni	Cr	Metal Weight (gms) Cu	Ni	Cr	Distribution (%) Cu	Ni	Cr
Leach Residue	2.02	.70	.31	4.30	.0141	.0063	.0869	3.32	.19	4.79
Copper Precipitate	2.02	20.00	15.70	.43	.4040	.3171	.0087	95.24	9.32	.48
Nickel Precipitate	5.12	.12	59.93	2.94	.0061	3.0684	.1504	1.44	90.21	8.29
Chromium Solution	881	--	.0011	1.78	--	.0096	1.5682	--	.28	86.44
Original Sample*	16.5	2.57	20.61	11.00	.4242	3.4014	1.8142	100.00	100.00	100.00

* Only the weight of the original sample was determined directly. Analysis for Cu, Ni and Cr in the original sample is derived from the analysis of the other products.

Having obtained satisfactory extraction of the three economic metals, it remained to recover the metals from the leach solution as separate products suitable for sale to existing markets. The sulphide precipitation route for copper and nickel was selected due to the almost quantitative precipitation anticipated and the fact that base metal smelters process copper and nickel sulphide mineral concentrates and the sulphide precipitates would be compatible with these existing smelter feeds. It was known that a critical pH existed at which copper and nickel could be precipitated selectively as sulphides, but it was necessary to determine this pH empirically. Efforts were made to adjust the pH of the leach solution with caustic soda and then to subsequently employ sodium sulphide as the precipitant. This proved to be difficult to accomplish with precision on a small scale because the sodium ion from the sodium sulphide had the effect of modifying pH in addition to precipitating the metals. The use of caustic as a pH modifier in conjunction with sulphide as a precipitate is well reported in the literature, and is the basis for the projected commercial process. Due to time and budget restrictions on the experimental programme and the fact that clean separations were required as the design basis for the process plant, sodium sulphide alone was employed in our testing and had the dual function of pH modifier and precipitant for copper and nickel. In future work on this process, a bench scale programme will be required to determine precisely the judicious combination of caustic and sodium sulphide which is required to obtain the critical pH and sulphide ion necessary for selective precipitation of copper and nickel.

A very selective precipitation of copper and nickel into copper and nickel sulphide concentrates was obtained in the final test carried out at the Ontario Research Foundation (Exhibit 5.3). In addition, extraction of all three metals from the sludge was high; 96.7 for copper, 99.8 for nickel and 95.2 for chromium. Had the leach residue been washed, the extractions would have been even higher.

A plasma scan of the final chromium-bearing solution is given in Exhibit 5.4. This analysis was the design basis for the chromium hydroxide precipitation section; no actual $Cr(OH)_3$ precipitation tests were carried out. However, all chromium in the solution was in the trivalent state, and hydroxide precipitation of trivalent chromium is well established on an industrial scale.

EXHIBIT 5.4

ANALYSIS OF CHROMIUM PREGNANT SOLUTION OBTAINED IN LABORATORY LEACHING

pH - 4.0

Specific Gravity - 1.024

Analysis (mg/l):

Cr^{+6}	- .01	Na	- 9800
Cr^{3}	- 1780	K	- 25
Ni	- 10.90	Ti	- 1.30
Cu	- .10	Mn	- 5.50
Be	- .13	P	- 1.30
Bo	- 65	Ba	- .50
Sb	- 2.5	Zr	- .25
Sr	- 2.5	Pb	- 1.30
Yt	- .13	Zn	- .50
Sc	- .05	Vn	- .25
Si	- 53	Sn	- 1.50
Al	- 12	Co	- .25
Fe	- 210	Mo	- .50
Mg	- 260	Ag	- .50
Ca	- 1300	Cd	- .25

5.2 METALLURGICAL BALANCE AND PRODUCTION SCHEDULE

The annual metallurgical balance for the projected metal recovery plant is based generally on the metal extractions and product analyses contained in the final ORF testwork (Exhibit 5.3) and on the anticipated feedstock quantity and composition as determined by the survey of the 15 largest sludge generators in southern Ontario (see Exhibit 4.1).

This projected metal balance, based on an available sludge feed of 7800 tonnes per year (dry basis), is presented in Exhibit 5.5.

Due to the very small scale of the process plant, it was decided to size the plant to operate only 16 hours/day, 5 days/week. The design basis, therefore, is an operating schedule of 75 hours weekly (allowing 1.0 hour per day for start-up and shut-down) and a plant availability of 85.0%. This equates to an hourly rate of 2,447 kilograms (dry basis) of sludge. All equipment, with the exception of the product dryers, is sized to process this quantity of sludge. The dryers will operate on a 24 hour basis, 5 days/week.

EXHIBIT 5.5

PROJECTED ANNUAL METAL BALANCE

BASIS: DAILY PROCESSING OF 31.20 TONNES DRY SLUDGE, 250 DAYS/YEAR

Product	Weight (Tonnes)	Assay (%)			Metal Weight (Tonnes)			Recovery (%)		
		Cu	Ni	Cr	Cu	Ni	Cr	Cu	Ni	Cr
Leach Residue	780.8	1.70	.30	5.76	13.26	2.34	44.93	3.40	.20	4.80
Chromium Hydroxide Product	2246.39		.156	36.00	--	3.51	808.70	--	.30	86.40
Cu Concentrate	1088.10	34.12	10.00	.43	371.28	108.81	4.68	95.20	9.30	.50
Ni Concentrate	1788.71	.31	59.00	4.34	5.46	1055.34	77.69	1.40	90.20	8.30
Plant Feedstock	7800.00	5.00	15.00	12.00	390.00	1170.00	936.00	100.00	100.00	100.00

5.3.1 Process Description

General

The process plant is designed to treat 3200 kilograms (dry basis) of sludge per operating day. The plant will operate 15 hours per day, five days per week. One hour per day is allowed for start-up and shut-down. The nickel, copper and chromium hydroxide precipitate dryers will operate 24 hours per day, 5 days per week and one operator will be present on the final shift of the day to attend them.

The plant will be located on serviced land in the Kitchener-Waterloo area. The plant building will be a pre-engineered structure and will be of rigid frame construction enclosed by sandwich type insulated steel roof deck and wall cladding panels. Effluent from the plant will consist of a washed leach residue product which is inert and will be shipped to a local municipal waste landfill and a heavy metal-free barren liquor at pH 8.5 which will be discharged to the sanitary sewer system. The nickel and copper sulphide precipitates will be shipped in 1.72 tonne bulk bags to the Inco smelter at Copper Cliff, Ontario. The chromium hydroxide precipitate will be shipped in semi-bulk bags to an Ontario chromium refractory/chromium chemical producer.

The flowsheets developed for the plant are presented as Exhibits 5.6 and 5.7.

Sludge Handling and Pug Milling

Sludge will be received and stored in the 5.352 m^3 dumpster bins currently utilized for shipment to landfill sites. Sludge pickups are coordinated to control sludge inventory at the plant at a maximum of one week's plant throughput ($\pm$57 bins).

Individual bins will be transported by fork-lift truck and dumped in a 7.656 m^3 pug mill feed hopper. A 914 mm belt feeder will withdraw sludge from the feed hopper and discharge it into a stainless steel twin screw pug mill which will break down and slurry the sludge, which in its "as received" state retains its filter cake structure. Hydrochloric acid and process water will be sprayed into the pug mill to slurry the sludge resulting in a product slurry density of approximately 5.0% solids.

The pug mill will discharge drop into an agitated 3.281 m x 3.281 m FRP dilution tank. A pulp density controller will maintain the slurry density in the dilution tank at 3.0% solids w/w.

Slurry from the dilution tank will gravitate to the first in a train of four agitated 3.281 m dia. x 3.281 m FRP leaching vessels, which will provide a total residence time of 60 minutes. Hydrochloric acid may be added via a loop from the HCl storage tank to the pug mill, dilution tank and each of the four leaching tanks. Most of the acid will be added to the pug mill and dilution tank in order to maximize the available leaching time, and a pH recorder/controller will maintain the terminal pH in the last leach tank at .7.

The leach pulp discharging from the final leach tank will be pumped by a 51 mm x 51 mm centrifugal pump to a 1,000 mm x 1,000 mm plate-and-frame filter press equipped with hydraulic plate shifter and vibrator to permit automated cake discharge. The cake will be thoroughly washed with strong caustic soda solution and transported to a local landfill for disposal.

Press filtrate (pregnant solution) will report to the first of two agitated 3.281 m x 3.281 m FRP pH adjustment tanks where caustic soda will be added in two stages to adjust the pH to 1.15 for copper precipitation. Caustic soda addition will be controlled by a pH recorder/controller.

Discharge from the second pH adjustment tank will gravitate to the first of two agitated 3.281 m x 3.281 m copper precipitation tanks. Sodium hydrosulphide solution will be added to both stages to precipitate copper as the sulphide. Total residence time in both tanks is 30 minutes.

Overflow from the second stage copper precipitation tank will be pumped by a 51 mm x 51 mm centrifugal pump to another 1,000 mm x 1,000 mm plate-and-frame press with automated discharge. The copper sulphide cake will be thoroughly washed with process water to remove all traces of chromium/nickel bearing filtrate. The copper sulphide filter cake will discharge into a 9.959 m^3 FRP storage bin.

Copper filter cake will be withdrawn from the bin by a screw feeder and delivered to a 1.219 m dia. x 9.144 m long direct fired, co-current flow rotary dryer where moisture content will be reduced from 75% to 10%, while producing a nodulized, free-flowing product. Dryer discharge will drop into 1.724 tonne semi-bulk bags for shipment to the Inco smelter at Copper Cliff, Ontario.

Filtrate from the copper filter press will report to the first of two agitated 3.281 m x 3.281 m FRP pH adjustment tanks to adjust the pH to 4.0 for Ni precipitation. Caustic soda addition to both tanks will be controlled by a pH recorder/controller.

Overflow from the second pH adjustment tank will report to the first of two agitated 3.281 m x 3.281 m FRP nickel precipitation tanks. Sodium hydrosulphide solution will be added to both stages to precipitate Ni as the sulphide. Total residence time in both tanks is 30 minutes.

Overflow from the second stage nickel precipitation tank will be pumped by a 51 mm x 51 mm centrifugal pump to a 1,200 mm x 1,200 mm plate-and-frame press with automated discharge. The nickel sulphide press cake will be thoroughly washed with process water to remove all traces of chromium-bearing filtrate. The nickel sulphide filter cake will discharge directly into a 14.405 m^3 storage bin.

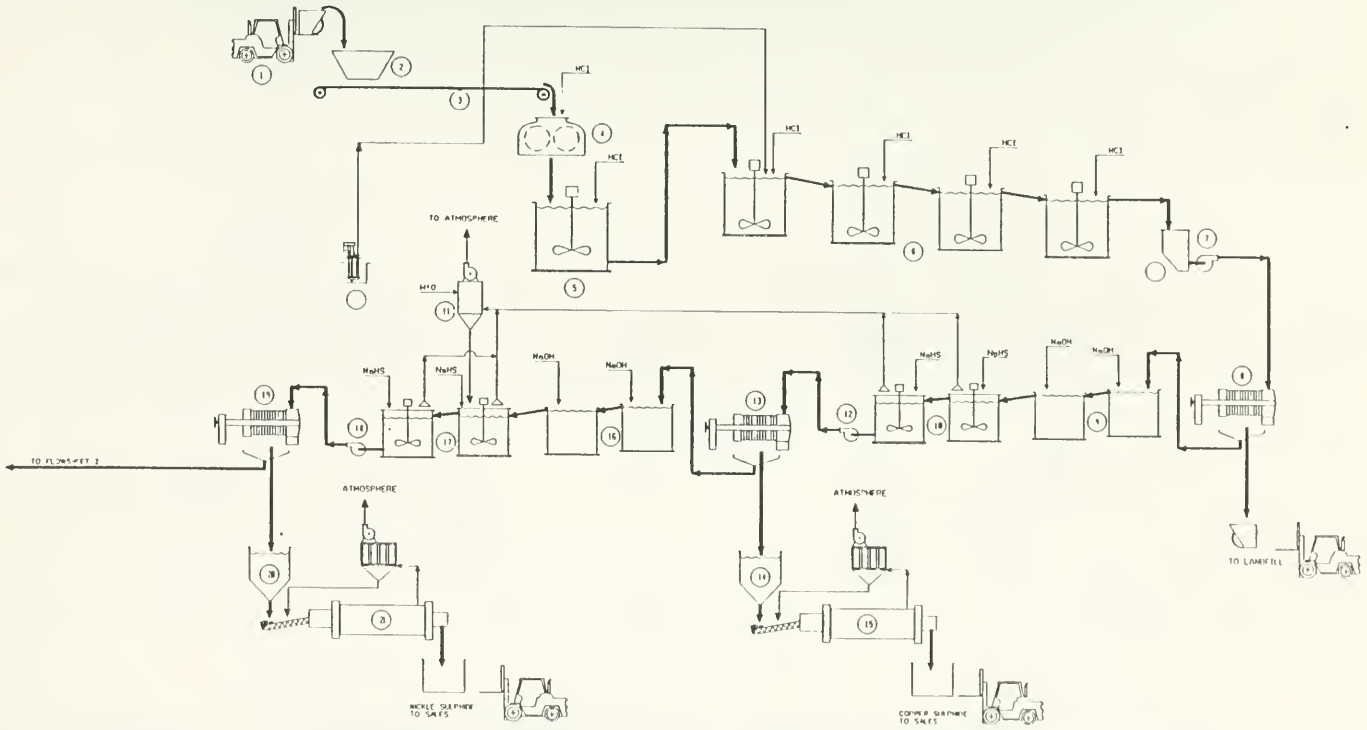
Nickel sulphide filter cake will be withdrawn from the bin by a screw feeder and delivered to a 1.524 m dia. x 12.192 m direct fired, co-current flow rotary dryer where moisture content will be reduced from 75.0% to 10.0%, while producing a

nodulized, free-flowing product. Dryer discharge will drop into 1.724 tonne semi-bulk bag containers which will be shipped to the Inco smelter at Copper Cliff, Ontario.

Filtrate from the nickel sulphide filter press will report to the first in a train of four agitated 3.281 m x 3.281 m FRP chromium precipitation tanks, with a total residence time of 58 minutes. Caustic soda will be added via a loop from the caustic storage tank to all four vessels as required to precipitate all heavy metals as hydroxides. A pH recorder/controller system will maintain the terminal pH in the first tank at 8.5.

The chromium hydroxide slurry will gravitate to a 5.182 m dia. x 5.283 m clarifier. Clear overflow will report to the sanitary sewer. Settling tank underflow will be pumped by a 51 mm x 51 mm centrifugal pump to a 1,200 mm x 1,200 mm plate-and-frame filter press. Clear filtrate will report to the sanitary sewer and the chromium hydroxide cake will be stored in a 23.35 m^3 storage bin.

Filter cake will be withdrawn from the bin by a screw feeder and dried in a 1.829 m dia. x 12.192 direct fired rotary dryer, which will discharge a free-flowing product at 10% moisture. The dried product will discharge directly into 1.724 tonne semi-bulk bags for shipment to an Ontario chrome chemical plant.



ITEM NO.	No REQD	DESCRIPTION
1	1	FORK LIFT TRUCK
2	1	0.5 m³ PUG MILL SURGE HOPPER
3	1	914mm PUG MILL FEED CONVEYOR
4	1	PUG MILL
5	1	DILUTION TANK C/W AGITATOR 3.28m DIA x 3.25m
6	4	LEACH TANKS C/W AGITATORS 3.28m DIA x 3.28m
7	1	CENTRIFICAL PUMP 51mm x 51mm
8	1	PLATE AND FRAME FILTER PRESS 48"x48" 30 FRAMES
9	2	Cu pH ADJUSTMENT TANKS C/W AGITATORS 3.28m DIA x 3.28m
10	2	Cu PRECIPITATION TANKS C/W AGITATORS 3.28m DIA x 3.28m
11	1	28.3m³ SCRUBBER C/W FAN AND PUMP
12	1	CENTRIFUGE PUMP 51mm x 51mm

ITEM NO.	No REQD	DESCRIPTION
13	1	PLATE AND FRAME FILTER PRESS 48 x 48 30 FRAMES
14	1	Cu CAKE STORAGE BIN 2.43m DIA x 3.35m CON. AL BOTTOM
15	1	Cu ROTARY DRYER 1.29m DIA x 3.66m C/W DUST COL & FEEDER
16	2	NaOH ADJUSTMENT TANKS C/W AGITATORS 3.28m DIA x 3.28m
17	2	PRECIPITATION TANK C/W AGITATORS 3.28m DIA x 3.28m
18	1	PUMP 51mm x 51mm
19	1	PLATE AND FRAME FILTER PRESS 48"x48" 30 FRAMES
20	1	Ni CAKE STORAGE BIN 2.74m DIA x 3.05m CONICAL BOTTOM
21	1	Ni ROTARY DRYER 1.524m DIA x 12.192m C/W DUST COL & FEEDER

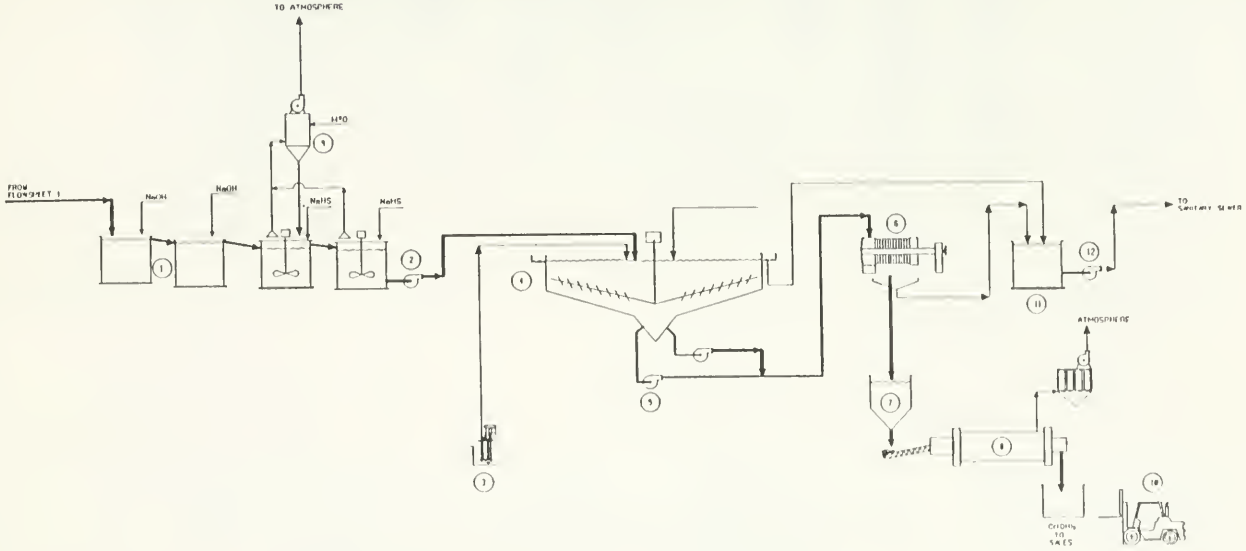
ITEM NO.	No REQD	DESCRIPTION

METAL RECOVERY PLANT
ENVIRONMENT CANADA PROJECT

FLOWSHEET NO.1
PUG MILLING, LEACHING, Cu-Ni PRECIPITATION & FILTRATION

R.L.PYNE

SIZE A1



ITEM NO	QTY REQD	DRAWING NO	DESCRIPTION	WEIGHT kg/UNIT
1	4		C.S.A. REACTION TANKS (2 @ 4.5) 3.02m DIA x 3.02m	
2	1		CENTRIFUGAL PUMP 51mm x 51mm	
3	1		SUMP	
4	1		CLARIFIER 5.182m DIA x 7.283	
5	2		CENTRIFUGAL PUMP 51mm x 51mm	
6	1		PLATE AND FRAME FILTER PRESS 915 x 915 87 FRAMES	
7	1		CAKE STORAGE BIN 3.048m DIA x 2.87m CONICAL BOTTOM	
8	1		ROTARY WATER COOLED DRUM 915 DIA x 2.87m CONICAL SCRUBBER AND DUST COLL	
9	1		28.5m³ SERIES RECYCLE TANK AND PUMP	
10	1		FORK LIFT TRUCK	

ITEM NO	QTY REQD	DRAWING NO	DESCRIPTION	WEIGHT kg/UNIT

ITEM NO	QTY REQD	DRAWING NO	DESCRIPTION	WEIGHT kg/UNIT

METAL RECOVERY PLANT
ENVIRONMENT CANADA PROJECT

FLOWSHEET NO.2
$Cr(OH)_3$ RECOVERY
PRECIPITATION & FILTRATION

R.L.PYNE

SIZE A1

5.3.2 Design Criteria

General

Average daily throughput (dry basis)		- 31,200 kgs
Plant availability, %		- 85.0
Maximum design hourly throughput (15 hrs/day, 5 days/wk)		- 2,447 kgs
Average metal concentration:	Cu	- 5.0%
	Ni	- 15.0%
	Cr	- 12.0%
Sludge H_2O content, %		- 60.0
Solids specific gravity		- 2.29
Sludge bulk density (as received), kg/m^3		- 1,282

Sludge Storage

One weeks supply stored in bins used for transport, kgs (dry basis)	- 156,000

Pug Milling

Operating period		- 15 hours/day
Hourly rate:	Dry basis	- 2,447 kg/hr
	Wet weight	- 6,118 kg/hr
	Sludge volume	- 4.77 m^3/hr
Spray water volume		- 42.732 m^3/hr
Pug mill discharge, % solids		- 5.0% solids

Dilution Tank

Feed rate	- 798 l/min
Tank size	- 3.281 m x 3.281 m
Active volume	- 20,005 l
Residence time	- 15 minutes
Product density, % solids	- 3.0

Leaching

Pulp density, % solids		- 3.0
Feed rate		- 1,345 l/min
Number of stages		- 4
Tank size		- 3.281 m dia. x 3.281 m
Active volume		- 20,005 litres/stage
Residence time		- 60 minutes
HCl consumption		- 3.03 kg/kg dry feed
Material of construction		- FRP
Leach extractions:	Cu	- 96.0%
	Ni	- 99.0%
	Cr	- 95.0%
Terminal pH		- .7

Leach Residue Filtration

Filter type		- plate-and-frame pressure filter
Filtration rate		- 6.97 kg/m^2/h
Filter feed slurry density		- .30% solids
Cake moisture		- 75.0%
Wash ratio (cake moisture displacement)		- 2.0
Wash solution:	1st Wash	- NaOH solution
	2nd Wash	- NaOH solution

Cu Precipitation

pH adjustment:	Feed rate	- 1,360 l/min
	Number of stages	- 2
	Tank size	- 3.281 m x 3.281 m
	Material of construction	- FRP
	Active volume	- 20,005 litres/stage
	Residence time	- 15 min/stage
	pH modifier	- NaOH
	Initial pH	- .7
	Terminal pH	- 1.15
Sulphide precipitation:		
	Feed rate	- 1,360 l/min
	Number of stages	- 2
	Tank size	- 3.281 m x 3.281 m
	Material of construction	- FRP
	Active volume	- 20,005 l/stage
	Residence time	- 15 min/stage
	Precipitant	- NaH S

Cu Precipitate Filtration

Filter type	- plate-and-frame pressure filter
Filtration rate	- 6.97 kgs/m^2/h
Filter feed, % solids	- .42
Cake moisture	- 75.0%
Wash ratio (cake moisture displacement)	- 2.0
Wash solution:	- process water

Ni Precipitation

pH adjustment:	Feed rate	- 1,374 l/min
	Number of stages	- 2
	Tank size	- 3.281 m x 3.281 m
	Material of construction	- FRP
	Active volume	- 20,005 l/stage
	Residence time	- 14 min/stage
	pH modifier	- NaOH
	Initial pH	- 1.15
	Terminal pH	- 4.0

Ni Precipitation (Cont'd.)
Sulphide precipitation:

Feed rate	- 1,374 l/min
Number of stages	- 2
Tank size	- 3.281 m x 3.281 m
Material of construction	- FRP
Active volume	- 20,005 l/stage
Residence time	- 14 min/stage
Precipitant	- NaH S

Ni Precipitate Filtration

Filter type	- plate-and-frame pressure filter
Filtration rate	- 7.35 kgs/m^2/hr
Filter feed, % solids	- .68 solids
Cake moisture	- 75.0%
Wash ratio (cake moisture displacement)	- 2.0
Wash solution:	- process water

Copper Sulphide Precipitate Drying

Dryer type	- 1.219 m dia. x 9.144 m direct fired, co-current flow rotary dryer
Feed rate (dry basis)	- 181.0 kg/hr
Feed moisture content	- 75.0%
Product moisture content	- 10.0%
Maximum gas temperature	- 871°C
Discharge temperature	- 107°C
Exhaust gas temperature	- 121°C
Exit gas velocity	- 70.0 m/min
Specific heat (solids)	- 211 joule/kg/°K
Fuel consumption	- 13,437,616 kilojoules/tonne CuS precipitate

Nickel Sulphide Precipitate Drying

Dryer type	- 1.524 m dia. x 12.192 m direct fired, co-current flow rotary dryer
Feed rate	- 299.0 kg/hr
Feed moisture content	- 75%
Product moisture content	- 10%
Maximum gas temperature	- 871°C
Discharge temperature	- 107°C
Exhaust gas temperature	- 121°C
Exit gas velocity	- 70.0 m/min
Specific heat (solids)	- 211 joule/kg/°K
Fuel consumption	- 13,437,616 kilojoules/tonne Ni S precipitate

$Cr(OH)_3$ Precipitation	
Feed rate	- 1383
Number of stages	- 4
Tank size	- 3.281 m x 3.281 m
Material of construction	- FRP
Active volume	- 20,005 l/stage
Residence time, total	- 58 minutes
Precipitant	- NaOH
Initial pH	- 4.0
Final pH	- 8.5
$Cr(OH)_3$ Filtration	
Filter type	- plate-and-frame pressure filter
Filtration rate	- 7.26 kgs/m^2/hr
Filter feed, % solids	- .80
Cake moisture	- 75.0%
Wash ratio (cake moisture displacement)	- 2
Wash solution	- process water
$Cr(OH)_3$ Cake Drying	
Dryer type	- 1.829 m dia. x 12.192 m direct fired, co-current flow rotary dryer
Feed rate	- 375.0 kgs/hr
Feed moisture content	- 75.0%
Product moisture content	- 10.0%
Maximum gas temperature	- 871°C
Discharge temperature	- 107°C
Exhaust gas temperature	- 121°C
Exit gas velocity	- 70.0 m/min
Specific heat (solids)	- 211 joule/kg/°K
Fuel consumption	- 13,437,616 kilojoules/ tonne $Cr(OH)_3$ precipitate
Reagents	
Hydrochloric acid (20° Baume):	
Consumption	- 6385 l/hr
Storage capacity	- 102,800 l
Caustic soda (50% liquid):	
Consumption	- 2238 l/hr
Storage capacity	- 102,800 l
Sodium hydrosulphide (45% liquid):	
Consumption	- 970 l/hr
Storage capacity	- 20,005 l/hr

SECTION 6.0

CAPITAL COST ESTIMATE

SECTION 6.0

CAPITAL COST ESTIMATE

6.1 BASIS OF ESTIMATE

Prices for all major process equipment items are budget prices obtained from vendors for new, specific units. Process equipment for metallurgical plants is tax exempt and no sales taxes have been applied to these prices.

Construction materials and labour costs were factored from equipment costs on the basis of statistical relationships of commodity and labour costs to process equipment costs prevailing in current projects at a similar scale and location. They are based upon the premise that construction will be carried out by a local general contractor employing all of the required trades on a local, direct-hire basis.

Indirect capital costs were estimated on the basis of current costs at similar projects and are rationalized in Section 6.4.

All capital costs are in 1988 dollars. The estimate has an implied accuracy of $\pm$20.0%.

6.2 CAPITAL COST ESTIMATE SUMMARY

Fixed capital cost for the metal recovery plant is estimated to be $5,224,800. Working capital is estimated to be $1,706,000.

The capital cost summary is presented on the following page and the detailed process equipment list is given in Section 6.3.

Capital Cost Summary

Item	Cost ($)
Purchased equipment cost	1,966,800
Equipment installation	492,000
Piping, material and labour	197,000
Electrical, material and labour	374,000
Instrumentation	236,000
Building and land	650,000
Plant services (process water system, sewers)	98,000
Site improvements (fences, roads, rail spur, etc.)	100,000
Sub-Total, Physical Plant Cost	4,113,800
Initial inventory of spares	50,000
Consultants, Environment	75,000
Construction indirects	200,000
Engineering and construction management	300,000
Contingency	411,000
Head Office costs	75,000
Sub-Total, Fixed Capital Cost	5,224,800
Working capital	1,706,000
Total, Capital Cost	6,930,800

6.3 PLANT EQUIPMENT LIST

Item	Quantity	KW	Cost ($)
Front end loader with fork attachment	1	-	150,000
Pug mill package including feed hopper, belt feeder and SS pug mill	1	7.5	28,000
Dilution tank, 3.281 m x 3.281 m, FRP, c/w four baffles	1	-	9,211
Dilution tank agitator, 5.08 cm dia. x 254.0 cm long, 81.3 cm dia. axial flow turbine, rubber-lined carbon steel	1	2.2	4,734
Leach tanks, 3.281 m x 3.281 m, FRP, c/w four baffles	4	-	36,844
Leach tank agitators, 5.08 cm dia. x 254.0 cm long, 81.3 cm dia. axial flow turbine, rubber-line carbon steel	4	9.0	18,936
51 mm x 51 mm x 203 mm centrifugal pump, cat iron	1	29.8	5,200
1,000 mm x 1,000 mm, 35 chamber plate-and-frame filter press	1	-	69,500
Copper pH adjustment tanks, 3.281 m x 3.281 m, FRP, c/w four baffles	2	-	18,422
Copper pH adjustment tank agitators, 5.08 cm dia. x 254.0 cm long, 81.3 cm dia. axial flow turbine, rubber-lined carbon steel	2	4.5	9,648
Copper precipitation tanks, 3.281 m x 3.281 m, FRP, c/w four baffles	2	-	18,422
Copper precipitation tank agitators, 5.08 cm dia. x 254.0 cm long, 81.3 cm dia. axial flow turbine, rubber-lined carbon steel	2	4.5	9,648
51 mm x 51 mm x 203 mm centrifugal pump, cast iron	1	29.8	5,200
1,000 mm x 1,000 mm, 49 chamber plate-and-frame filter press	1	-	85,000

Item	Quantity	KW	Cost ($)
Copper filter cake storage bin, 2.438 m dia. x 3.353 m high, conical bottom, FRP	1	-	9,000
Copper rotary dryer, 1.219 m dia. x 9.144 m, direct-fired, co-current flow, stainless steel shell c/w lifters, chains, bag filter and screw feeder	1	13.1	220,000
Nickel pH adjustment tanks, 3.281 m x 3.281 m, FRP, c/w four baffles	2	-	18,422
Nickel pH adjustment tank agitators, 5.08 cm dia. x 254.0 cm long, 81.3 cm dia. axial flow turbine, rubber-lined carbon steel	2	4.5	9,648
Nickel precipitation tanks, 3.281 m x 3.281 m, FRP, c/w four baffles	2	-	18,422
Nickel precipitation tank agitators, 5.08 cm dia. x 254.0 cm long, 81.3 cm dia. axial flow turbine, rubber-lined carbon steel	2	4.5	9,648
51 mm x 51 mm x 203 mm centrifugal pumps, cast iron	1	29.8	5,200
1,200 mm x 1,200 mm, 53 chamber plate-and-frame filter press	1	-	96,000
Nickel filter cake storage bin, 2.743 m dia. x 3.658 m high, conical bottom, FRP	1	-	11,000
17 m^3/min scrubber for nickel and copper precipitation tanks, c/w fan and pump	1	2.5	5,000
Nickel rotary dryer, 1.524 m dia. x 12.192 m, direct-fired, co-current flow, stainless steel shell c/w lifters, chain section, bag filter and screw feeder	1	14.9	299,000
Leaching area 5.08 cm, vertical floor sump pump, rubber-lined	1	1.9	4,000

Item	Quantity	KW	Cost ($)
Chromium precipitation area 5.08 cm vertical floor sump pump, rubber-lined	1	1.9	4,000
Chromium precipitation tanks, 3.281 m dia. x 3.281 m, FRP, c/w four baffles	4	-	36,844
Chromium precipitation tank agitators, 5.08 cm dia. x 254.0 cm long, 81.3 cm dia. axial flow turbine, rubber-lined carbon steel	4	9.0	19,256
Chromium precipitation clarifier, 5.182 m dia. x 5.283 m high, FRP, c/w peripheral overflow launder	1	-	51,000
Chromium press feed pump, 51 mm x 51 mm x 203 mm centrifugal, cast iron	1	29.8	5,200
1,200 mm x 1,200 mm, 67 chamber, plate-and-frame filter press for chromium	1	-	110,000
Chromium filter cake storage bin 3.048 m dia. x 4.267 m straight side, conical bottom, FRP	1	-	17,000
Chromium cake rotary dryer, 1.829 m dia. x 12.192 m direct fired, co-current flow, stainless steel shell c/w lifters, chain section, bag filter, and screw filter	1	18.7	375,000
Hydrochloric acid storage tank, 5.182 m dia. x 5.283 m, FRP	1	-	51,000
Hydrochloric acid pump, 38 mm x 25 mm centrifugal, FRP c/w mechanical seal, base, motor, etc.	1	.7	3,452
Caustic soda storage tank, 5.182 m dia. x 5.283 m high, FRP	1	-	51,000
Caustic soda pump, 38 mm x 25 mm centrifugal, Alloy 20, c/w mechanical seal, motor, etc.	1	1.1	4,883

Item	Quantity	KW	Cost ($)
Sodium hydrosulphide storage tank, 3.048 m dia. x 3.084 m high, FRP	1	-	9,211
Sodium hydrosulphide pump, 38 mm x 25 mm centrifugal, Alloy 20, c/w base, motor, double mechanical seal, etc.	1	1.1	4,883
Compressor, 100 PSI, 445 ACFM		56.0	50,000
Total		276.8	1,966,834

6.4 INDIRECT COSTS

6.4.1 Initial Inventory of Spares

This allowance includes the cost of procuring all critical spares required to ensure continuity in operation of the process plant. The quantity shown is an estimate based on total cost of moving process equipment.

6.4.2 Consultants, Environment

An allowance of $75,000 has been provided for these services which primarily reflect the cost of preparing an environmental impact statement and applications for permits.

6.4.3 Construction Indirects

This allowance includes all costs for temporary installations (temporary power, water supply, sewage), fuel for construction, small tools, consumables, supervision, contractor's fees, vehicles, equipment, freight to the site, bonds and insurances. The allowance is based on direct construction costs.

6.4.4 Engineering and Construction Management

This item includes engineering design, procurement and construction management services. The allowance of $300,000 is based on the total physical plant cost.

6.4.5 Contingency

The contingency allowance is estimated at 10% of the physical plant cost.

6.4.6 Head Office Costs

A lump sum of $75,000 has been provided for this item. It is intended to reflect the salary allocation of an owner's project manager during the engineering and construction period.

6.5 WORKING CAPITAL

Working capital is budgeted to cover operating costs for three months. The rationale for this estimate is that the smelter does not pay for the nickel and copper concentrate until three months after receipt. Revenues from chromium hydroxide sales could also be delayed three months subsequent to production.

6.6 COMMENTS ON CAPITAL COST ESTIMATE

Equipment prices are based on the purchase of new equipment. Good refurbished equipment for a plant of this size is currently available and could reduce the total capital cost estimate by approximately $1,000,000, as well as having the effect of shortening the construction schedule due to reduced delivery time for used equipment.

SECTION 7.0

OPERATING COST ESTIMATE

SECTION 7.0

OPERATING COST ESTIMATE

The operating costs developed for the metal recovery plant are based on an annual processing rate of 7,800 dry metric tonnes of sludge, which is achieved in 250 operating days, 16 hours/day. A two week annual shut-down will be in effect. The assumed site of the plant is on serviced land in the Kitchener-Waterloo area.

The plant complement will consist of a plant manager, a chief operator/mechanic and a process operator on each of two shifts, plus one process operator on the third shift to supervise operation of the product dryer.

The processing ratio of 2,447 kilogram/hr is in fact small pilot plant scale for the extractive metallurgical industry and two men/shift currently operate similar plants of this size. A substantial allowance has been made for instrumentation and automation in the capital cost estimate, further reducing labour requirements.

Direct operating costs for labour, supplies, power and fuel have been estimated using current prices in effect in the Kitchener/Waterloo area. Prices for supplies include freight and handling charges to the proposed plant site.

Indirect operating costs are pro-rated from current costs prevailing at similar industrial plants.

Plant Operating Cost Estimate Summary

Item	Annual Cost ($)	Cost/Tonne ($)
Direct Operating Cost	6,692,204	857.97
Indirect Operating Cost	157,500	20.19
Total Operating Cost	6,849,704	878.17

7.1 PLANT DIRECT OPERATING COST SUMMARY

Item	$/Year	$/Tonne
Staff and labour	235,200	30.15
Operating supplies	6,309,898	808.96
Maintenance and miscellaneous supplies	102,500	13.14
Power	44,606	5.72
Total, Direct Operating Cost	6,692,204	857.97

7.2 PLANT DIRECT OPERATING COST - STAFF AND LABOUR

Category	Number Required	Hourly Rate ($)	Annual Wages ($)	Fringe Benefits ($)	Total/ Man-Year ($)	Total/ Year ($)	$/Tonne Sludge Processed
Plant Manager	1	--	60,000	19,200	79,200	79,200	10.15
Chief Operator/ Mechanic	2	15.00	31,200	7,800	39,000	78,000	10.00
Process Operator	3	10.00	20,800	5,200	26,000	78,000	10.00
Sub-Total	6					235,200	30.15

7.3 PLANT DIRECT OPERATING COST - OPERATING SUPPLIES

Item	Rate kg/tonne	Delivered Cost $/kg	Cost $/year	Cost $/tonne Sludge Processed
Hydrochloric Acid	3,030	.115	2,717,910	348.45
Caustic Soda	1,062*	.202	1,672,112	214.37
Sodium Hydrosulphide	234**	.790	1,443,449	185.06
Sub-Total			5,833,471	747.88
Semi-Bulk Bags for Shipping Products			82,575	10.59
Natural Gas		.165 /m^3	312,621	40.08
Process Water	4,040	.96 /m^3	30,252	3.88
Diesel Fuel		.475 /l	10,797	1.38
Filter Media			40,182	5.15
Sub-Total			476,427	61.08
Total, Operating Supplies			6,309,898	808.96

* Consumption is based on NaOH requirement to neutralize all HCl added to process.

** Consumption based on 1.25 times stoichimetric ratio of NaHS to Cu and Ni precipitated.

7.4 PLANT DIRECT OPERATING COST - MAINTENANCE AND MISCELLANEOUS SUPPLIES

Item	$/Year	$/Tonne
Analytical Laboratory Contract*	38,000	4.87
Office Supplies	1,500	.19
Lubricants	1,500	.19
Repair Parts	40,000	5.13
Electrical Maintenance Contract	20,000	2.57
Miscellaneous Tools & Supplies	1,500	.19
Sub-Total	102,500	13.14

* Basis: 30 analyses/day.

7.5 PLANT DIRECT OPERATING COST - POWER

Total Demand Load = 222 kw
Total Annual Power Consumption = 888,000 KWH

Kitchener-Wilmot Hydro Schedule

Demand Charge

1. First 50 kw = No charge
2. Next 172 kw = $3.95/kw/month

Energy Charge

1. First 250 kwh = $.0735/kwh
2. Next 12,250 kwh = $.0542/kwh
3. Next 61,500 kwh = $.0383/kwh

Calculations:

Power Consumption/Month = 888,000/12 = 74,000 kwh
Demand Charge = 172 x $3.95 = $679.40
Energy Charge = (250 x .0735) + (12,250 x .0542) + (61,500 x .0383)
= $3,037.78
Demand + Energy Charge = $679.40 + $3,037.78
= $3,717.18
Cost/kwh = $3,717.18/74,000 = $.0502
Annual Cost = 12 x $3,717.18 = $44,606
Cost/Tonne Sludge Feed = $44,606/7,800 = $5.72

7.6 INDIRECT PLANT OPERATING COSTS

Item	$/Year	$/Tonne
Communications	2,500	.32
Permits, Licenses & Fees	2,000	.26
Property Taxes	10,000	1.28
Insurance on Plant and Equipment	50,000	6.41
Audit and Legal	5,000	.64
Travel Expenses	3,000	.38
Consultant's Fees	10,000	1.28
Head Office Costs	75,000	9.62
Total, Indirect Costs	157,500	20.19

7.7 COMMENT ON OPERATING COST

The impact of the cost of chemical reagents on the total operating cost estimate is major, accounting for 87.0% of the total direct operating cost.

A very significant reduction in operating costs could be realized if a source of waste hydrochloric acid were available to replace purchased virgin acid. It is quite possible that pickling liquor from steel plants in the Hamilton area could be utilized for leaching, with simultaneous recovery of heavy metals contained in the pickling liquor. This possibility must be investigated in any future work on the process.

SECTION 8.0

PRODUCT MARKETING

SECTION 8.0

PRODUCT MARKETING

8.1 COPPER AND NICKEL SULPHIDE CONCENTRATES

Sales terms for purchase of the copper and nickel sulphide concentrates produced by the metal recovery plant were sought from four primary base metal refineries in Canada. Terms were requested on the basis of products similar to the copper and nickel sulphide precipitates obtained in the final experimental work at the Ontario Research Foundation. The results of these inquiries are summarized below:

Falconbridge Limited

Although Falconbridge had supplied tentative payment terms in January, 1987, they expressed no interest in purchasing these products in June, 1988. They indicated that they were working on their own process to extract metals from hydroxide sludge.

Sherritt-Gordon Limited

A sample of the "as generated" sludge was submitted to Sherritt to determine their interest in refining this material at their Fort Saskatchewan nickel refinery. They reported that they could not accept it at their plant due to the high chromium content. Sale of enriched copper and nickel concentrates to Sherritt was not considered due to the costly freight haul to the Alberta plant vis-a-vis Inco's smelter at Sudbury, and also due to the fact that their process does not produce refined copper, i.e. the copper would have to be returned to Eastern Canada for refining.

Noranda Mines Limited

Noranda expressed a willingness to purchase the copper concentrate. However, they have no nickel refinery and do not pay for any nickel contained in the

copper concentrate. As the copper concentrate will contain significant quantities of nickel, Noranda would not be competitive with Inco, who have both a copper and nickel smelter at their Sudbury complex.

Inco Limited

The most favourable terms for purchase of the copper and nickel sulphide concentrates were received from Inco Limited. Correspondence from Inco setting out these terms is given in Appendix 2.0. The "net smelter return" (realized value of the products after all deductions and charges) is derived from these terms, and the calculation of the net smelter return is given in Section 8.1.2, 8.1.3 and 8.1.4 following.

8.1.1 Inco Net Smelter Return for Nickel Sulphide Concentrate

1. Payments (basis: 1.0 metric dry tonne of concentrate @ 59.0% Ni)

Deduct .5% from Ni assay of concentrate and pay for 92% of the balance at $5.00/lb (U.S. funds).

$$\therefore \text{Payment} = (.590 - .005) \times .92 \times 2204.6 \times \$5.00 \times 1.2230 \text{ (Cdn. Exchange)}$$
$$= \$7,255.54 \text{ (Cdn.)/metric tonne Ni concentrate}$$

2. Charges

$$\text{Smelting charge} = \$120.00 \text{ (Cdn.)/short dry ton of concentrate}$$
$$= \$120.00 \times 1.1023$$
$$= \$132.28/\text{metric tonne of concentrate}$$

$$\text{Refining charge} = \$.85 \text{ (Cdn.)/lb of accountable Ni}$$

$\therefore$ Refining charge = (.590 - .005) x .92 x 2204.6 x $.85
= $1,008.54/metric tonne of concentrate

3. Total Charges = Smelting charge + refining charge
= $132.28 + 1,008.54
= $1,140.82

4. Net Smelter Return (NSR)/tonne Ni Concentrate

NSR = Payments - Charges
= $7,255.54 - 1,140.82
= $6,114.72

5. Net Smelter Return for Ni Concentrate per tonne Sludge Feedstock

From annual metal balance (Exhibit 5.5), the net smelter return per tonne of sludge feedstock will be:

$$\frac{\$6,114.72 \times 1,788.71}{7,800}$$
= $1,402.24

8.1.2 Inco Net Smelter Return for Copper Sulphide Concentrate

The copper sulphide concentrate contains nickel and copper, both of which metals are paid for by Inco.

1. Payments (basis: 1.0 dry metric tonne of concentrate assaying 10.00% Ni and 34.12% Cu)

Ni Payment

Deduct .5% from Ni assay of concentrate and pay for 92% of the balance at $5.00/lb (U.S. funds)

$\therefore$ Payment = (.10 - .005) x .92 x 2204.6 x $5.00 x 1.2230 (U.S. Exchange)
= $1,178.25/tonne Cu concentrate

Cu Payment

Deduct .5% from Cu assay of concentrate and pay for 90% of the balance at LME Grade A settlement price (currently $1.18 Cdn./lb.) less $.03 U.S. ($.037 Cdn.).

$\therefore$ Payment = (.3412 - .005) x .90 x 2204.6 x ($1.180 - $.037)
= $762.46/tonne Cu concentrate

Total Payment = Ni payment + Cu payment
= $1,178.25 + 762.46
= $1,940.71/tonne Cu concentrate

2. Charges

Smelting charge = $120.00 (Cdn.)/short dry ton of concentrate
= $120 x 1.1023 = $132.28/metric tonne of Cu concentrate

Ni Refining charge = $.85 Cdn./lb of accountable Ni
∴ Ni refining charge = (.10 - .005) x .92 x 2204.6 x $.85
= $163.78/metric tonne Cu concentrate

Cu Refining charge = $.20 Cdn./lb of accountable Cu
= (.3412 - .005) x .90 x 2204.6 x $.20
= $133.41/metric tonne Cu concentrate

3. Total Charges = Smelting charge + Ni Refining charge + Cu Refining charge
= $132.28 + $163.78 + $133.41
= $429.47/metric tonne Cu concentrate

4. Net Smelter Return (NSR)/tonne Cu Concentrate

NSR = Total Payments - Total Charges
= $1,946.71 - $429.47
= $1,511.24

5. Net Smelter Return for Copper Concentrate per tonne Sludge Feedstock

From annual metal balance (see Exhibit 5.5), the annual net smelter return per tonne sludge feedstock will be:

$$\frac{\$1,511.24 \times \$1,088.10}{7,800}$$
= $210.82

8.1.3 Total Inco Net Smelter Return/tonne Plant Feedstock

Total NSR = NSR/tonne for Ni concentrate + NSR/tonne for Cu concentrate
= $1,402.24 + $210.82
= $1,613.06/tonne sludge feedstock

Note: No freight charges for shipping concentrates to Copper Cliff have been applied in this net smelter return calculation. It was decided to ignore the freight charges ($30.71/tonne concentrate) because all freight charges on the feed to the plant and its products are certain to be substantially lower than current charges to platers for transport of sludge to Sarnia and disposal fees at the landfill site (currently $250.00/tonne dry sludge).

8.2 CHROMIUM HYDROXIDE PRECIPITATE

The production of a marketable chromium commodity from the trivalent chromium chloride solution obtained by hydrochloric acid leaching of sludge was explored in considerable detail. In particular, the feasibility of manufacturing high unit value products such as chromic acid or sodium dichromate (the basic materials for chromium chemicals manufacture) via ion exchange and electrolytic oxidation of the chromium solution was investigated. This route had to be rejected due to the very high capital and operating costs and also because of considerable uncertainty that a sufficiently pure product could be obtained to meet current specifications. It became very clear that a much larger scale of operation would be required to make the manufacture of end-user chromium chemicals viable.

Inquiries were made to chromium chemical producers, chromium refractory brick manufacturers, and ferrochromium producers in the U.S. and Canada concerning the requirement for chromium raw materials. The only serious interest was in a product which would replace chromite imported primarily from the U.S.S.R. and South Africa. A chromium hydroxide product precipitated from a solution similar to that

obtained in the laboratory testing programme (see Exhibit 5.4) and containing approximately 36.0% Cr, 4.25% Fe and 1.0% Si was stated by several producers to be acceptable as a replacement for chromite ore. No demand appeared to exist for an "upgraded" chromium product as an intermediate in their processes.

The prices suggested for purchase of such a product varied from $.20 - $.30 per pound of chromium contained in the hydroxide precipitate. The product would require drying to a maximum 10% moisture content. In the case of most of the U.S. producers, plants were distant from the proposed Kitchener, Ontario site of the metal recovery plant, and the freight charges would be prohibitive.

The most practical proposal was received from Metallurg (Canada) Limited, suggesting a price of $.20/lb of contained Cr for a product analyzing 36.0% chromium, 4.25% iron and 1.0% silica (see Appendix 3.0 - "Metallurg (Canada) Limited - Terms for Purchase of Chromium Hydroxide"). The product would be destined for the Ontario market and freight charges were estimated to be approximately $18.00/metric tonne. These terms are the basis for the chromium hydroxide revenue projection.

It is obvious that the chromium content of the sludge is not a contributor to profit; the cost of chemical reagents, drying, and shipping of the precipitate exceeds the revenues from sale of the product. The rationale for chromium hydroxide production is in the return of this toxic metal to the industrial cycle, rather than consigning it to landfill.

8.2.1 Chromium Hydroxide Price

The most suitable market for this product, which would be located within an economic shipping radius of the proposed Kitchener metal recovery plant site, was Metallurg (Canada) Limited. The suggested purchase price was $.20/lb of contained chromium in the hydroxide precipitate.

8.2.2 Chromium Hydroxide Revenue

Annual revenue from chromium hydroxide sales will be 2,246.39 tonnes x 2,204.6 x .36 x $.20 = $356.572. Revenue per tonne of feedstock will be $356,572/7,800 = $45.71.

8.3 TOTAL SALES REVENUE

8.3.1 Transportation of Products

Freight on sulphide concentrates from the assumed plant site in the Kitchener/Waterloo area to the Inco smelter at Copper Cliff, Ontario and freight on the chromium hydroxide product to the Ontario market have been ignored in the revenue calculations. Current costs to electroplating shops for transportation and disposal of neutralized sludge are approximately $250.00/metric tonne. This credit would more than offset the transportation costs to ship the sludge to the metal recovery plant, shipe metal recovery plant leach residue to a local municipal waste landfill, and ship all of the plant's products to the market.

The cost of semi-bulk bags for shipping the products in included in the direct operating costs.

8.3.2 Total Sales Revenue

Total sales revenue projections are summarized in the table below:

Product	Annual Production (tonnes)	Revenue/ Tonne Product ($)	Annual Revenue ($)	Revenue/ Tonne Sludge ($)
Copper Concentrate	1,088.10	1,511,24	1,644,380	210.82
Nickel Concentrate	1,788.71	6,114.72	10,937,461	1,402.24
Chromium Hydroxide	2,246.39	158.73	356,572	45.71
Total Revenue			12,938,413	1,658.77

SECTION 9.0

ECONOMIC EVALUATION

SECTION 9.0

ECONOMIC EVALUATION

A cash flow projection for a one year preproduction period and nine years of production is given in Exhibit 9.1. It is assumed for purposes of this exercise that all capital is raised from equity sources. The economic evaluation indicates a discounted cash flow rate of return of _____% and a payback period of 2.2 years.

The input to the cashflow statement is explained under separate headings.

9.1 PRODUCTION

The production rates (dry sludge processed and plant products) are as given in the annual metal balance (Exhibit 5.5).

9.2 REVENUE

The net smelter return calculation for copper and nickel sulphide concentrates and the sales revenue for the chromium hydroxide precipitate are given in Sections 8.1.2, 8.1.3 and 8.2. The net smelter return for copper and nickel concentrate in the cashflow statement is the net smelter return in dollars for one tonne of product of each metal times the annual production in tonnes of each metal product. Chromium hydroxide revenue is the revenue in dollars per tonne or product times the annual production in tonnes.

9.3 OPERATING PROFIT

The operating profit is the sales revenue from the three plant products less the total operating costs, before deduction of corporation taxes.

9.4 CORPORATION TAXES

Corporation taxes are applied to operating profit at 33% after repayment of the capital investment.

9.5 NET EQUITY CASH AVAILABLE

The net equity cash available is the net cash flow after deducting corporation taxes and capital repayment from operating profits.

EXHIBIT 9.1
CASHFLOW SUMMARY ($)

	Year 1 (Design/ Construction)	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Production										
Tonnes Sludge Processed		7,800.00								
Tonnes Copper Conc. Produced		1,088.10								
Tonnes Nickel Conc. Produced		1,788.71								
Tonnes Chromic Hydroxide Produced		2,246.39								
Revenue						Years 3 to 10 Identical to Year 2				
Net Smelter Return - Copper Concentrate		1,644,380								
Net Smelter Return - Nickel Concentrate		10,937,461								
Sales Revenue - Chromic Hydroxide		356,572								
Total Sales Revenue		12,938,413								
Operating Cost										
Direct Operating Cost		6,692,204				Same as Year 2				6,692,204
Indirect Operating Cost		157,500				Same as Year 2				157,500
Total Operating Cost		6,849,704				Same as Year 2				6,849,704
Pre-tax Operating Profit		6,088,709				Same as Year 2				6,088,709
Corporation Taxes			1,731,384	2,009,274		Same as Year 4				2,737,254
Cash Flow Before Repayment of Capital		6,088,709	4,357,325	4,079,435		Same as Year 4				3,351,455
Capital Costs										
Fixed Capital Cost	5,224,800					Same as Year 2				
Working Capital		1,706,000				Same as Year 3				1,706,000
Working Capital Recovery					Same as Year 1					500,000
Salvage Value of Plant					Same as Year 1					
Total Capital Cost	5,224,800	1,706,000				Same as Year 3				5,557,455
Net Equity Cash Available	-5,224,800	4,382,709	4,357,325	4,079,435		Same as Year 4				3,351,455
Cumulative Equity Cash Total	-5,224,800	-842,091	3,515,234	7,594,669	11,674,104	15,753,539	19,832,974	23,912,409	27,991,844	33,549,299
Discounted Cash Flow Rate of Return (%)	81.75%									
Capital Payback	2.19 years									

SECTION 10.0

REFERENCES

SECTION 10.0

REFERENCES

1. Environment Canada, "Review of the Canadian Metal Finishing Industry: Consumption of Raw Materials and Options for Water Pollution Control". Report EPS 3-WP-75-2, Ottawa, 1975.

2. Environment Canada, "Overview of the Canadian Surface Finishing Industry: Status of the Industry and Measures for Pollution Control". Report EPS 2/SF/1, December 1987.

APPENDIX 1.0

ANALYSIS OF SLUDGE SAMPLES BY ASSAYERS' ONTARIO

Certificate of Analysis

Certificate No I-1760/ #6706 Date September 3, 1987

Received Aug 21/87 13 Samples of Sludges

Submitted by R.L. Pyne Metallurgical Consultant

ON DRY BASIS

Sample No.	Au oz/ton	Ag ppm	Cu %	Cr %	Ni %	Zn %	Moisture %
A	.004	<.1	.57	8.71	29.19	.12	19.73
B	.009	.3	7.27	21.12	12.83	<.1	43.71
D	.006	<.1	5.07	9.18	27.34	.53	12.87
E/A	.60	<.1	1.90	6.69	9.31	5.18	87.39
E/B	.002	<.1	1.99	19.45	13.95	.39	21.44
F	.002	<.1	1.47	7.26	18.45	.26	47.77
G	.003	<.1	3.77	3.97	18.98	.18	61.15
H	<.001	<.1	5.32	12.36	16.76	.96	63.56
I	.003	<.1	7.73	8.07	11.14	2.46	73.19
J	.002	<.1	3.49	17.34	13.93	1.43	55.94
K	.002	<.1	4.25	2.86	6.64	6.76	68.90
M	.001	<.1	.92	4.17	13.95	10.12	40.61
N	.003	2.5	13.33	10.20	18.47	2.99	24.88

ASSAYERS (ONTARIO) LIMITED

Per _____

J. van Engelen Mgr.

Certificate of Analysis

Certificate No MI-1808/6759 Date September 16, 1987

Received ~~R. L. Pyne~~ 2 Samples of Sludges

Submitted by Metallurgical Consultant Att'n: Mr. R. L. Pyne

	'C'	'L'
Moitsure	34.05	50.55 %
ON DRY BASIS		
Ni	1.95	11.88
Cu	.32	4.62
Zn	11.40	.33
Cr	2.62	.05

ASSAYERS (ONTARIO) LIMITED

Per _____

J. van Engelen Mgr.

APPENDIX 2.0

INCO PURCHASE TERMS FOR COPPER AND NICKEL SULPHIDE CONCENTRATES

FAX

June 21, 1988

TO: Rod Pyne
FAX: 416 363 5855

The following is an outline of terms for the purchase of copper/nickel sulphides to be used only for feasibility studies.

Materials:

1) "Copper sulphide" 360 tonnes per year.
Cu 54%, Ni 16%, Cr 0.7%, Zn < 0.2%.

2) "Nickel sulphide" 920 tonnes per year.
Cu 0.3%, Ni 59%, Cr 4.3%, Zn < 0.2%.

Both materials must be in a physical form and have a moisture content which would enable them to be handled through Inco's facilities without problems, ie not wet and sticky, not dusty. Note also that Inco's smelter has a limitation on chrome content of toll materials. The nickel sulphide is borderline and would have to be reviewed by smelter personnel. However for feasibility study the following terms may be used.

For material delivered f.o.b. Copper Cliff smelter in packaging suitable to the smelter.

1. Accountability

Nickel: 92% of the remainder after deducting 0.5 assay units.
Copper: 90% of the remainder after deducting 0.5 assay units.

2. Charges

Smelting CAN $120 per short dry ton.

Refining - Ni 85¢ per accountable pound.
Cu 20¢ per accountable pound. CAN

3. Payment for Accountable Metals

Ni LME Cash price for second month after receipt of material, with a maximum of US$5.00 per lb.

Cu LME Grade A Settlement price for second month after receipt of material less US3¢ per lb.

Regards,

Ross Morrison

Ross Morrison

APPENDIX 3.0

METALLURG (CANADA) LIMITED

TERMS FOR PURCHASE OF CHROMIUM HYDROXIDE

R.L. PYNE
METALLURGICAL CONSULTANT
Suite 1304
250 Queens Quay West
Toronto, Ontario M5J 2N2

Telephone: (416) 977-7574

16 September 1988

Mr. H.W. Campbell
A/Head
Residue Management System
Wastewater Technology Centre
P.O. Box 5050
Burlington, Ontario
L7R 4A6

Dear Herb:

Attached you will find five (5) copies of the draft report, "Preliminary Evaluation of Copper, Nickel and Chromium Recovery From Wastes Generated by the Metal Finishing Industry in Ontario".

I apologize for the delay in getting the project completed. Aside from the initial failure to obtain suitable products by the flotation process, much time was lost in investigations directed toward the production of end-user chromium products. After much cost estimating and many discussions with producers and consumers of chromium chemicals, it became clear that such a venture is just not viable on the scale that would apply for this type of plant.

I will be pleased to have your comments on the report and to answer any questions you may have on the data contained therein.

Yours very truly,

R.L. Pyne

RLP/jc
Encl.